DTU Library

Lemanczyk

Lemanczyk, Jerzy; Larsen, F. Holm

Published in:
I E E E Transactions on Antennas and Propagation

Link to article, DOI:
10.1109/8.1187

Publication date:
1988

Document Version
Publisher's PDF, also known as Version of record

Comparison of Near-Field Range Results

JERZY LEMANCZYK, MEMBER, IEEE, AND F. HOLM LARSEN, MEMBER, IEEE

Abstract—**Comparisons of measurements on a contoured beam antenna carried out at five independent European test ranges are presented. They include a compact antenna test range, two cylindrical near-field test ranges, and two spherical near-field test ranges. The comparisons illustrate problems in the determination of gain values and cross polarization, while the agreement in the copolar patterns and the peak directivity is very good.**

Introduction

MODERN satellite technology is placing ever more stringent requirements on antenna performance which in turn has placed increasing demands on the capabilities of antenna measurement ranges. Not only have conventional ranges been upgraded in terms of performance, but totally new techniques by which antennas can be measured have emerged. The development of planar, cylindrical, and spherical near-field test ranges as well as the various forms of the compact test range satisfies the need of measuring antennas in a controlled environment without loss of accuracy.

The performance and accuracy of new measurement ranges must be demonstrated prior to allowing acceptance testing of satellite antennas to be carried out. Even if one is convinced of the superiority of the new test techniques, it is required, given their complexity, to have new ranges thoroughly tested before actual use.

Therefore, the antenna measurement system verification is important. One way of verification is to have two or more independent antenna measurement systems carry out measurements on a common antenna with subsequent comparison of the results. The comparison of results from several ranges not only provides an opportunity for critically testing the hardware aspects of the particular antenna ranges but also tests the procedures used at the respective antenna ranges.

Comparisons between results of near-field measurements, far-field measurements, and compact range measurements can be found in several places in the literature [1]–[4]. What distinguishes the comparisons described in the present paper are

- the measurements were carried out at independent institutions in different countries, and
- the measurements involved cross polarization, peak directivity, and contours for a shaped beam antenna similar to a frequency reuse satellite antenna.

Manuscript received September 15, 1987. This work was supported by a contract from the European Space Agency.

The authors are with the Electromagnetics Institute, Technical University of Denmark, Building 348, DK-2800 Lyngby, Denmark.

IEEE Log Number 8821099.

Background

The Technical University of Denmark (TUD) has over the years, in cooperation with the European Space Agency (ESA), carried out research in spherical near-field testing. This has resulted in the TUD–ESA Spherical Near Field Antenna Test Facility [5], [6]. One of the main purposes of the facility as it evolved was to supply the European antenna community with experience related to spherical near-field testing as well as providing calibration services. The facility thus operates as an ESA pilot test range against which other antenna ranges employed on ESA projects can be compared.

Prior to any comparisons carried out with other ranges, the TUD facility carried out comparisons with itself; this is treated in another publication [16]. This involved measurements where various system parameters such as scan speed and antenna position were changed systematically and their results being investigated for any change. A convincing demonstration of the accuracy of a spherical near-field measurement is to carry out measurements at three distances such that the near fields are very different from each other. Close agreement of the resultant far fields can be obtained after transformation [7], [8], [16].

The Comparisons

The first comparison was between the spherical near-field test range at TUD, a cylindrical near-field test range at Messerschmitt–Bölkow–Blohm (MBB) [9], and the compact range at the Tekniske Hogschole Eindhoven (THE) [10]. The experiences gained from this first foray were used in a subsequent comparison, using the same antenna as previously, carried out between TUD, the cylindrical near-field range at British Aerospace plc (BAE) [11], and the spherical near-field range at Marconi Space Systems (MSS) [12].

The Antenna

The antenna must be mechanically stable and be well suited for travel. For satellite antennas, determination of peak gain and pointing are important exercises. Just as important is the measurement of cross polarization.

The antenna used for the two comparisons described in this paper was an offset-fed parabola designed and manufactured by MBB [13] as shown schematically in Fig. 1. Since the test ranges involved are intended for satellite antenna measurements, the chosen antenna had a shaped beam, though not designed for any particular coverage. As seen from a contour plot of its copolar radiation, Fig. 2, the antenna has broad radiation in the one plane while it is relatively narrow in the other.

0018-926X/88/0600-0845$01.00 © 1988 IEEE

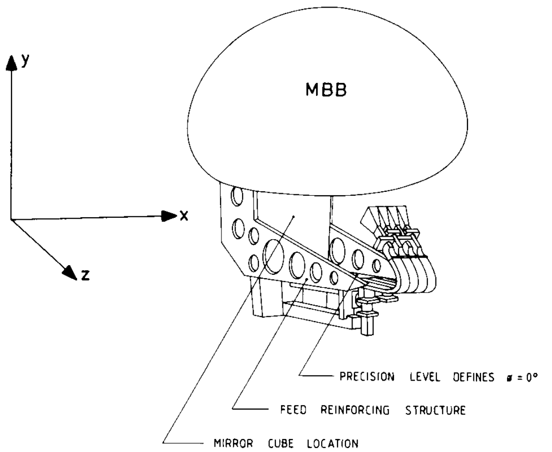


Fig. 1. Schematic of MBB antenna and coordinate system definition.

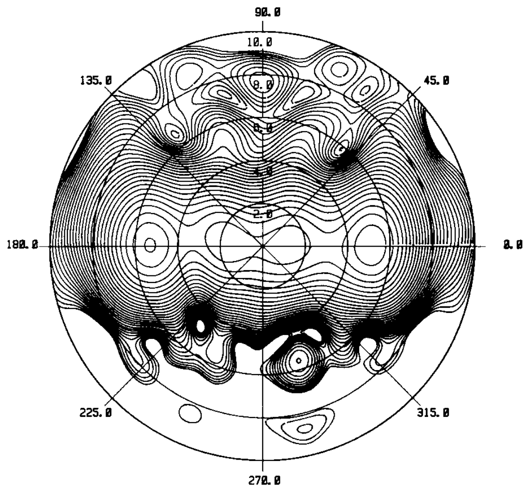


Fig. 2. Copolar amplitude contour plot for $\theta \leq 10°$. Contours are in 1-dB steps with additional contour at -0.1 dB relative to peak.

The co- and cross-polar components are here defined according to Ludwig's third definition [14]:

$$i_{\text{ref}} = \cos(\phi - \phi_0)\hat{\theta} - \sin(\phi - \phi_0)\hat{\theta} \quad (1)$$

$$i_{\text{cross}} = \sin(\phi - \phi_0)\hat{\theta} + \cos(\phi - \phi_0)\hat{\theta}. \quad (2)$$

In antenna calculations, one can usually align the co- and cross-polar components to be parallel to the x and y axes on the boresight (z axis). However, in near-field measurements, the antenna coordinate system is defined before the far-field polarization on boresight is known, and therefore it is convenient to be able to adjust the polarization reference. Hence the introduction of the polarization reference angle ϕ_0 in (1) and (2). The meaning of ϕ_0 is illustrated in Fig. 3. Once ϕ_0 is chosen, (1) and (2) determine the reference directions on the far-field sphere.

The coordinate system for the MBB antenna was defined by an optical mirror cube attached to the antenna. The cross-polar radiation, shown in Fig. 4, was defined in the cube's coordinate system with $\phi_0 = 0^0$. The cross polarization is very sensitive to the choice of ϕ_0 and the choice of $\phi_0 = 0^0$ will not necessarily be the optimum with respect to minimizing the cross polarization.

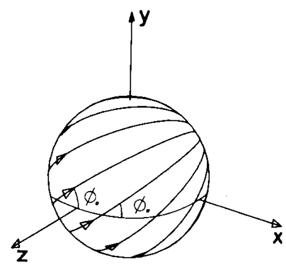


Fig. 3. Illustration of Ludwig third definition reference pattern and polarization reference angle ϕ.

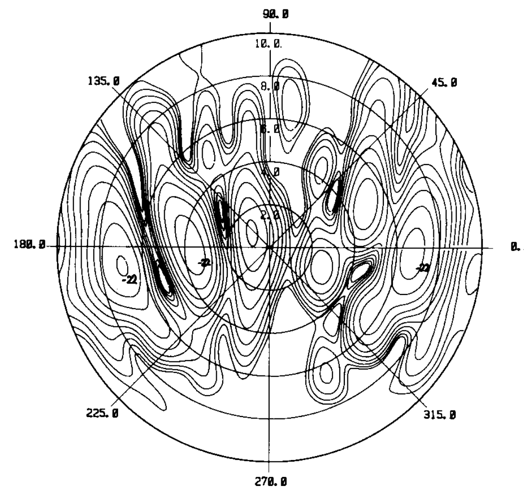


Fig. 4. Cross polar amplitude contour plot for $\theta \leq 10°$. Contours are in 2-dB steps starting at -22 dB relative to copolar peak as indicated.

The TUD–MBB–THE Comparison

As this was the first comparison to be attempted, problems in carrying out this task quickly appeared. The measurements at MBB and TUD were carried out with the antenna aligned after the optical mirror cube which was attached to the antenna structure. The far-field comparisons for the TUD and MBB results are shown in Figs. 5 and 6 which are the two principal planes of the antenna; note that the MBB data were supplied as amplitude only and thus could not be interpolated.

The results of a similar comparison between the TUD and THE measurements are shown in Fig. 7. Note that there is a different angular scale between the THE and MBB results. It can be seen that the agreement between TUD and each of the other two ranges was quite good but that there is a difference between the MBB and THE cross-polar results. This is due to a difference in the polarization reference angle which in the compact range is adjusted by rotating the feed horn of the compact range. It is more convenient to adjust the range polarization to obtain a null in the cross-polar far-field pattern rather than aligning relative to a mechanical reference. As both amplitude and phase for the two far-field components of the electric field are available from spherical near-field

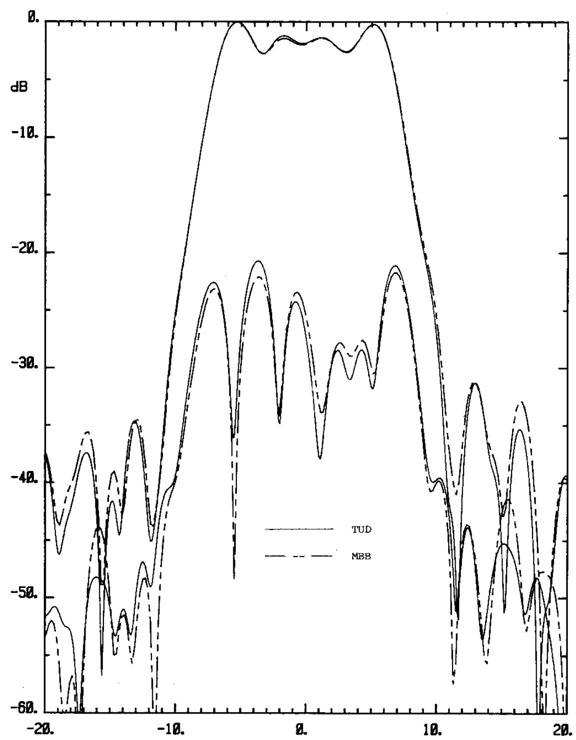


Fig. 5. *E*-plane comparison between TUD and MBB.

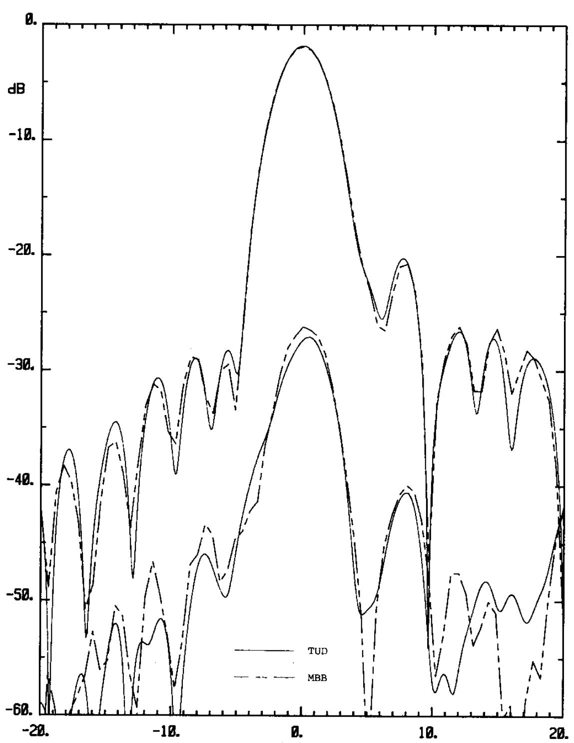


Fig. 6. *H*-plane comparison between TUD and MBB.

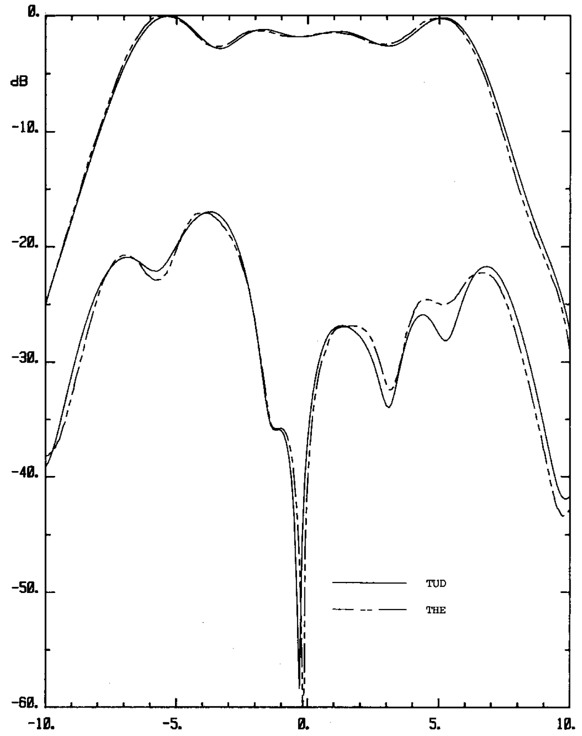


Fig. 7. *E*-plane comparison between TUD and THE. Polarization reference angle $=3.83°$.

measurements, the polarization reference angle for these data can be arbitrarily changed in the computer. The agreement for the *E*-plane as shown in Fig. 7 was obtained by changing the polarization reference angle for the TUD result to 3.83° with respect to the optical mirror cube mounted on the antenna.

Note that only radiation patterns were compared. In the case of the MBB results, only the *E*- and *H*-planes were provided while THE included the 45° and 135° planes, the latter being compared to the TUD results in Fig. 8. Discrepancies appear in the cross-polar results. The polarization reference angle for the TUD results in Fig. 8 was the same as that for Fig. 7. However, by changing the polarization reference angle to $\phi_0 = 0.33°$, the much better agreement shown in Fig. 9 was achieved. The main reason for this is that the polarization of the feed horn has been manually adjusted for each cut after the test antenna has been rotated. In the $\phi = 45°$ and 90° cuts (not shown), the optimum choice of ϕ_0 was 2.4° and 1.6°, respectively. However, the agreement in Fig. 9 is still not as good as in the *E*-plane (Fig. 7). The reason can be that the test antenna has been rotated about an axis which is not precisely perpendicular to the phase front of the compact range. It is also known that the polarization tilt angle of an offset-fed reflector varies slightly across the aperture, a problem which may further contribute to the one above. Table I provides a brief overview of some of the comparison results.

The TUD–BAE–MSS Comparison

Given the experience of the previously discussed comparison, a more ambitious program was planned for the second

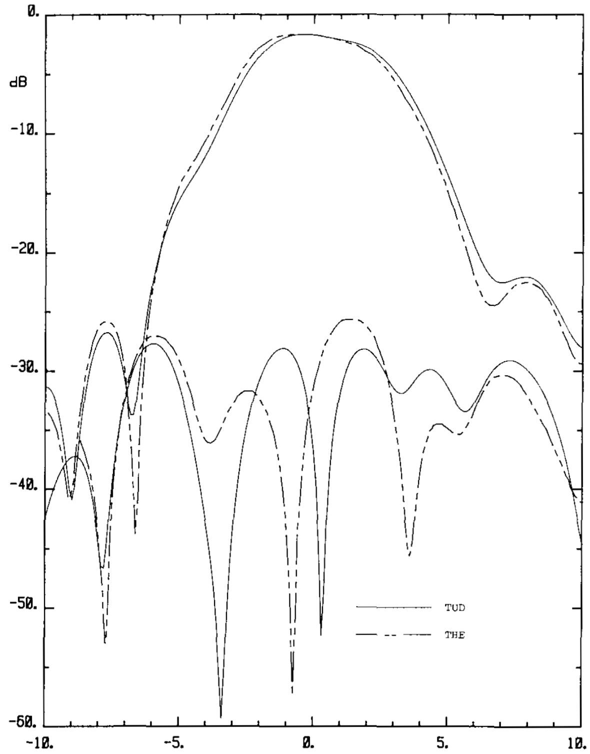


Fig. 8. 135°-plane comparison between TUD and THE. Polarization reference angle = 3.83° showing poor agreement.

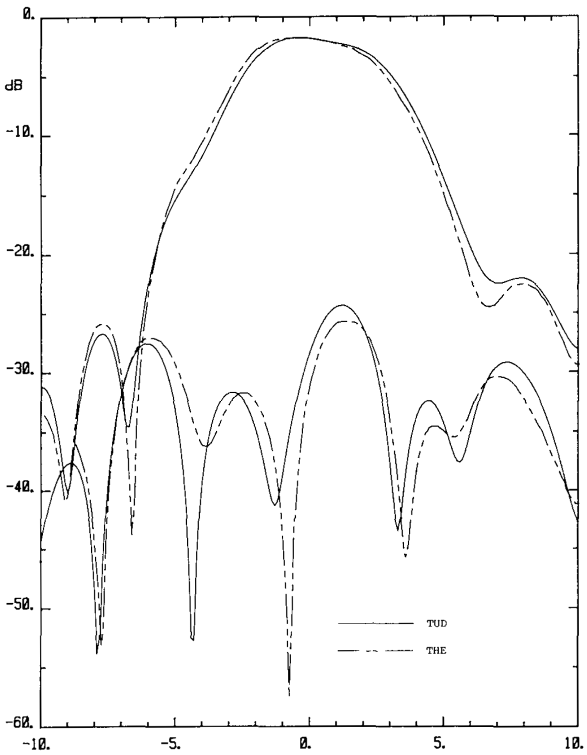


Fig. 9. 135°-plane comparison between TUD and THE. Best agreement with polarization reference angle = 0.33°.

TABLE I
FIELD POINT AMPLITUDES REFERRED TO THE COPOLAR PEAK

Parameter	Amplitude (dB) TUD	MBB	THE
$(\theta, \phi) = (5.1°, 0°)$	−0.19	−0.19	−0.13
$(\theta, \phi) = (7.6°, 90°)$	−20.2	−20.6	−22.2
E-plane cross	−20.8	−21.5	–
polarization maximum	−17.0	–	−17.2

round where, in addition to far-field radiation patterns, peak gain of the antenna was to be measured. It was also required that each measurement facility provide its results on magnetic tape in the optical cube's coordinate system with a minimum requirement of the E-, H-, and 45° planes. MSS, by virtue of their spherical near field system, provided their results over the entire far-field sphere in spherical coordinates. BAE had the necessary software to be able to interpolate their far-field data to the same grid. This meant that a more ambitious and revealing comparison could be undertaken, namely the comparison of radiation contours, and hence pointing.

In Figs. 10 and 11 can be seen the co- and cross-polar radiation patterns of the E-plane for all three test ranges. The data were plotted directly as provided with no rotations indicating that all three laboratories had provided their results in the coordinate system defined by the optical mirror cube. However, Fig. 12, which is a comparison of the two TUD H-plane measurements, indicates that all is not well in the Kingdom of Denmark. The plots show the H-planes from the two measurement campaigns carried out on the MBB antenna. A check of alignment data showed no error and the shift was ascribed to improper mounting of the antenna at TUD during its second visit. It was later realized that if too long a bolt was used to mount the antenna, it could protrude and push against the reflector mount without causing any displacement of the optical mirror cube.

This conjecture is born out when examining the contour plot in Fig. 13. Here is shown the −3-dB contour. It is to be seen that the first TUD measurement agrees well with the MSS and BAE results and that it is the second TUD measurement which indicates a shift of approximately 0.23° in theta between the two TUD measurements. The MSS data also appear to be slightly shifted and were estimated by MSS to be approximately 0.08° from the first TUD measurement and the BAE results. The agreement between the first TUD measurement and BAE is remarkable.

Gain values were obtained at all three ranges by near-field substitution with a standard gain horn. Peak directivities were also calculated by means of pattern integration. Two factors greatly influenced the gain comparison. One was the calibrated gain values for the standard gain horns, and the other was the influence of mismatches in the substitution. By the IEEE definition [15], gain is referred to the power accepted by the antenna. The mismatch correction factor used to obtain the IEEE gain value from a substitution measurement is

$$M = 10 \log \frac{(1-|\Gamma_H|^2)|1-\Gamma_S\Gamma_T|^2}{(1-|\Gamma_T|^2)|1-\Gamma_S\Gamma_H|^2} \tag{3}$$

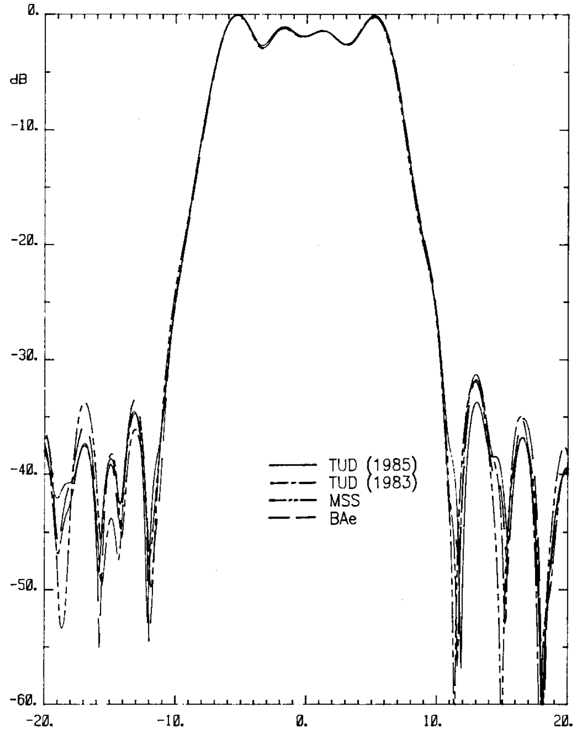


Fig. 10. *E*-plane copolar amplitude patterns for two TUD measurements, MSS and BAE. All data supplied in optical cube defined coordinate system.

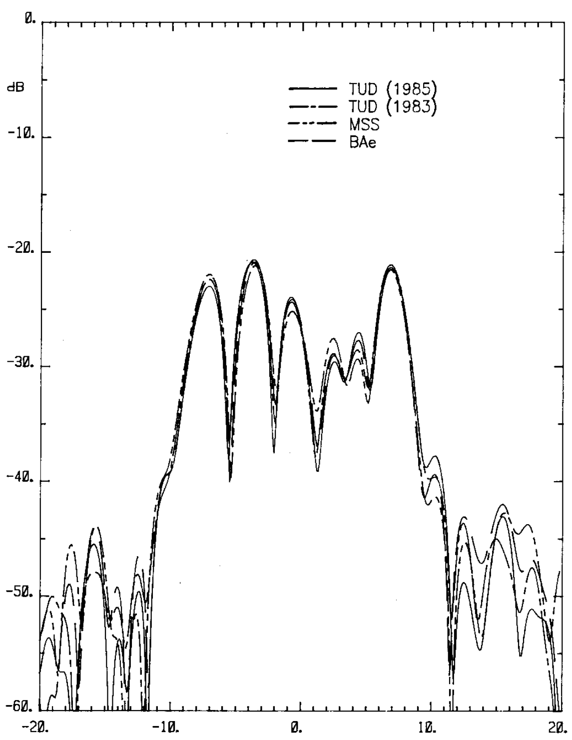


Fig. 11. *E*-plane cross polar amplitude patterns for two TUD measurements, MSS and BAE. All data supplied in optical cube defined coordinate system.

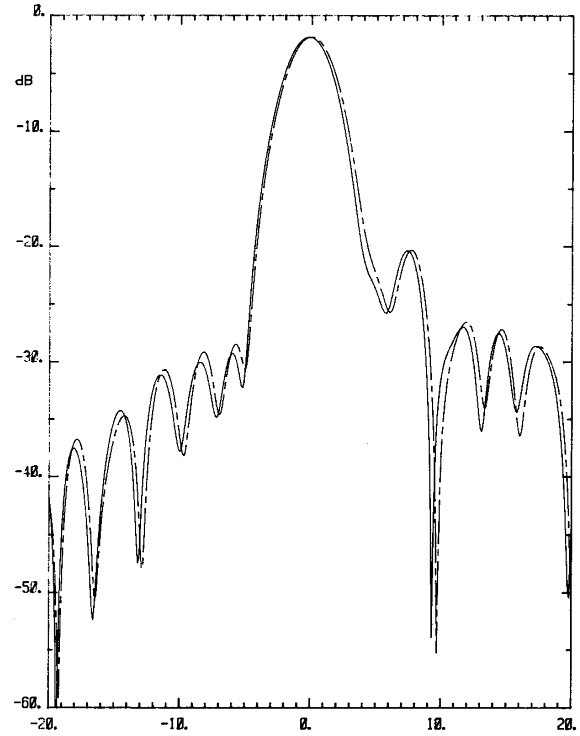


Fig. 12. *H*-plane comparison between two TUD measurement campaigns. Shift of beam was most probably due to improper mounting of antenna on model tower.

where

Γ_H complex reflection coefficient of the standard gain horn,
Γ_S complex reflection coefficient of the source,
Γ_T complex reflection coefficient of the test antenna.

Generally, Γ_H is small. At TUD, all the complex reflection coefficients were measured and the correction in (3) applied. These gain values are labeled as Gain1 in Table II. MSS and BAE assumed that their cable reflection coefficient Γ_S was small and omitted mismatch corrections. If $\Gamma_S = 0$, a gain value referred to the power delivered to the antenna is obtained which includes the reflection loss term $(1 - |\Gamma_T|^2)$; this is called the realized gain in the IEEE standard [15]. These gain values are called Gain2 in Table II. Measurement of Γ_T indicated Gain2 to be 0.17 dB lower than Gain1, the IEEE gain.

After compiling the gain values shown in Table II, it was discovered that the calibrated gain value for the standard gain horn used at MSS was inaccurate. It should also be noted that the standard gain horn at BAE was post calibrated, i.e., its gain was not known at the time of the BAE measurement. Had the proper gain value been available, the measurement of a gain greater than the directivity would have prompted further effort. The horn gain was determined at TUD by spherical near-field scanning of the horn, pattern integration, and subtraction of a calculated loss figure of the order of 0.01 dB.

The results in Table II thus illustrate that obtaining gain

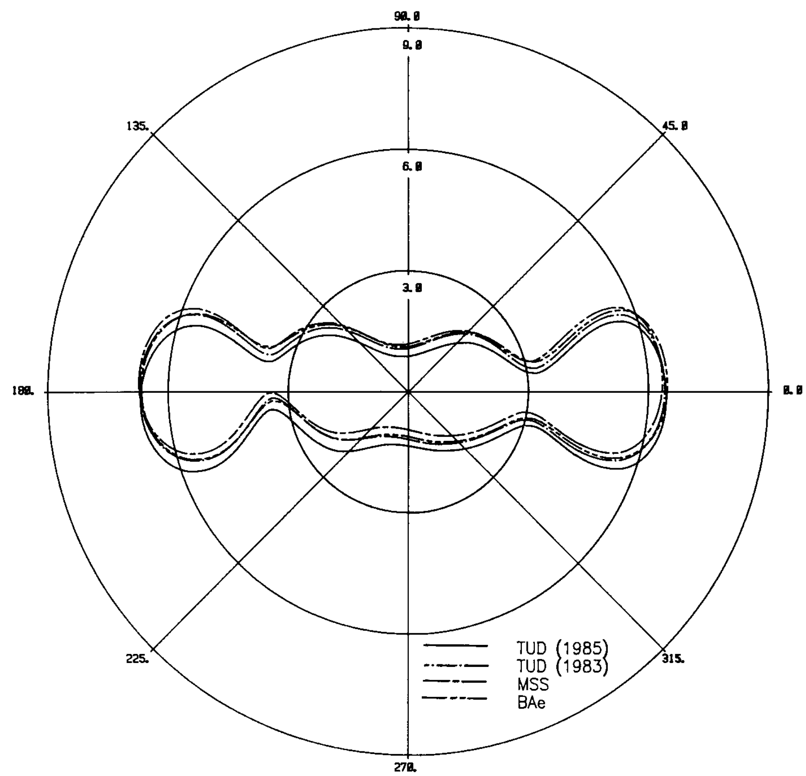


Fig. 13. −3-dB contour with respect to peak for two TUD measurements, MSS and BAE.

TABLE II
GAIN AND DIRECTIVITY[a]

Parameter	TUD (1983)	TUD (1985)	MSS	BAE
Gain1 (dBi)	29.59	29.67	—	—
Gain2 (dBi)	29.42	29.50	29.30	30.00
Directivity (dBi)	29.89	29.86	29.89	29.87

[a] Gain1 is the IEEE gain where the value is referred to the power accepted by the antenna. Gain2 on the other hand is a value referred to the power delivered to the antenna. MSS claims that recalibration of their gain standard increases their measured gain to Gain2 = 29.55 dBi.

values accurate to within 0.1 dB is difficult, while the agreement between the directivity values is remarkable. This indicates a good pattern agreement over much of the far-field sphere. In addition to mismatches, one more reason for the difficulties in obtaining the same accuracy for the gain as for the directivity is that the comparison with the horn is made at a single point in the near field. Thus errors from multiple reflections between antenna and probe (tower) plus short-term drift and changes in cable will influence the gain value directly. While these errors tend to be averaged out in calculation of far-field pattern and directivity.

Conclusion

Comparisons between antenna measurements carried out at different near-field ranges is a sound way to verify the accuracy of far-field determination. Generally, the weaknesses of the measurement systems or the procedures used will be revealed by comparisons to independent measurements. The experience with a contoured beam antenna presented in this paper shows that accurate results can be obtained for pattern shape, pointing and peak directivity. The cross-polar comparisons require a strict definition of the coordinate system and the polarization reference vectors. Absolute gain demands control over the reflection coefficients as well as an accurately calibrated standard gain horn. Even though the agreement for the peak directivities is within a few hundredths of a dB, the determination of gain values for contoured beam antennas with an agreement to within 0.1 dB between independent test ranges is still to be demonstrated.

Acknowledgment

The authors would like to acknowledge the contributions of J. Hammer, ESTEC, in these tasks.

References

[1] R. C. Johnson, H. A. Ecker, and J. S. Hollis, "Determination of far-field antenna patterns from near-field measurements," *IEEE Trans. Antennas Propagat.*, vol. AP-21, pp. 1668–1694, Dec. 1973.

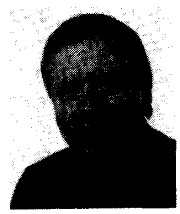
[2] E. B. Joy, W. M. Leach, G. P. Rodrigue, and D. T. Paris, "Applications of probe-compensated near-field measurements," *IEEE Trans. Antennas Propagat.*, vol. AP-26, pp. 379–389, May 1978.

[3] K. R. Carver and A. C. Newell, "A comparison of independent far-field and near-field measurements of large spaceborne planar arrays with controlled surface deformations," in *Proc. IEEE AP-S Symp.*, Seattle, WA, June 1979, pp. 494–497.

[4] J. J. Tavormina and D. W. Hess, "Spherical near-field antenna measurements with the scientific-atlanta model 2022," in *Proc. 1980 AMTA Meeting,* Redondo Beach CA.
[5] J. E. Hansen, *The TUD-ESA Spherical Near Field Antenna Test Facility, Lyngby, Denmark,* ESA Publication BR-19, Apr. 1984.
[6] J. E. Hansen, Ed., *Spherical Near-Field Antenna Measurements.* London: Peter Peregrinus, 1988.
[7] F. H. Larsen, "Spherical near-field scanning," *Satellite Communication Technology,* Mittra, Ed. Amsterdam, The Netherlands: North Holland, 1983, ch. 9.1.
[8] J. Lemanczyk, "Accuracy of spherical near field testing of an MBB contoured beam antenna," Electromagnetics Inst., Technical Univ. of Denmark, R281, Dec. 1983.
[9] C. P. Fischer, "Cylinrical near field test facility for large satellite antennas." in *Proc. 13th European Microwave Conf.,* Nurnberg, FRG, 1983, pp. 829–834.
[10] V. J. Vokurka, "Compact antenna range," in *Satellite Communication Technology,* Mittra, Ed. Amsterdam, The Netherlands: North Holland Publishers, 1983, ch. 9.3.
[11] Z. F. Voyner, B. Howe, A. D. Craig, J. Sheppard, and W. M. Kennerly, "Near field probe-scanning antenna measurement facility," in *Proc. 2nd IEE Int. Conf. Antennas and Propagation,* York, England, Apr. 1981, pp. 278–282.
[12] P. R. Miller and P. R. Cowles, "Implementation and use of a large near field antenna test facility," in *Proc. 4th IEE Int. Conf. Antennas and Propagation,* Coventry, England, Apr. 1985, pp. 483–488.
[13] D. Fasold, H. Pesche, and G. Saulich, "Elliptische Offset-Reflektorantennen mit Einfach- und Mehrfachspiesesystemen fur Satellitenanwendungen," in *Proc. URSI Symp.,* Kleinhuebach, FRG, 1979, pp. 155–163.
[14] A. C. Ludwig, "The definition of cross polarization," *IEEE Trans. Antennas Propagat.,* vol. AP-21, pp. 116–119, Jan. 1973.
[15] *IEEE Standard Test Procedures for Antennas,* IEEE Standard 149, 1979.
[16] J. Lemanczyk, J. E. Hansen, and F. H. Larsen, "Evaluation of the spherical near field range at the Technical University of Denmark," in *Proc. AP-S Int. Symp.,* Boston, MA, 1984.

Jerzy Lemanczyk (S'75–S'78–M'80) was born in Montreal, PQ, Canada in 1953. He received the B.Sc.E.E. degree from Concordia University, Montreal, PQ, Canada, and the M.Eng. degree from McGill University, Montreal, in 1975 and 1978, respectively.

In two periods between 1977 and 1980 he was a Visiting Researcher at the Electromagnetics Institute, The Technical University of Denmark, Lyngby. Since 1980 his relationship with EMI, TUD became more permanent and he has participated in the further development of spherical near-field antenna measurements and its applications. He is also responsible for the ESA Standard Gain Facility at TUD providing ESA projects with calibrated gain standards.



F. Holm Larsen (M'74) was born in Copenhagen, Denmark, in 1948. He received the M.Sc. and Ph.D. degrees in electrical engineering from the Technical University of Denmark, Lyngby, in 1973 and 1982, respectively.

Since 1974 he has been with the Electromagnetics Institute, Technical University of Denmark, Lyngby, from 1985 as an Assistant Professor. He has participated in the development of a spherical near-field measurement system for the European Space Agency, and also worked for TICRA A/S, Copenhagen, as a consultant in near-field transformation software. He is a contributing author to a recent book on spherical near-field measurements published by Peter Perigrinus in 1988.